Study of feasibility of electronics and detectors to determine bunch by bunch beam properties for the EIC ring-ring designs

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EIC R&D meeting

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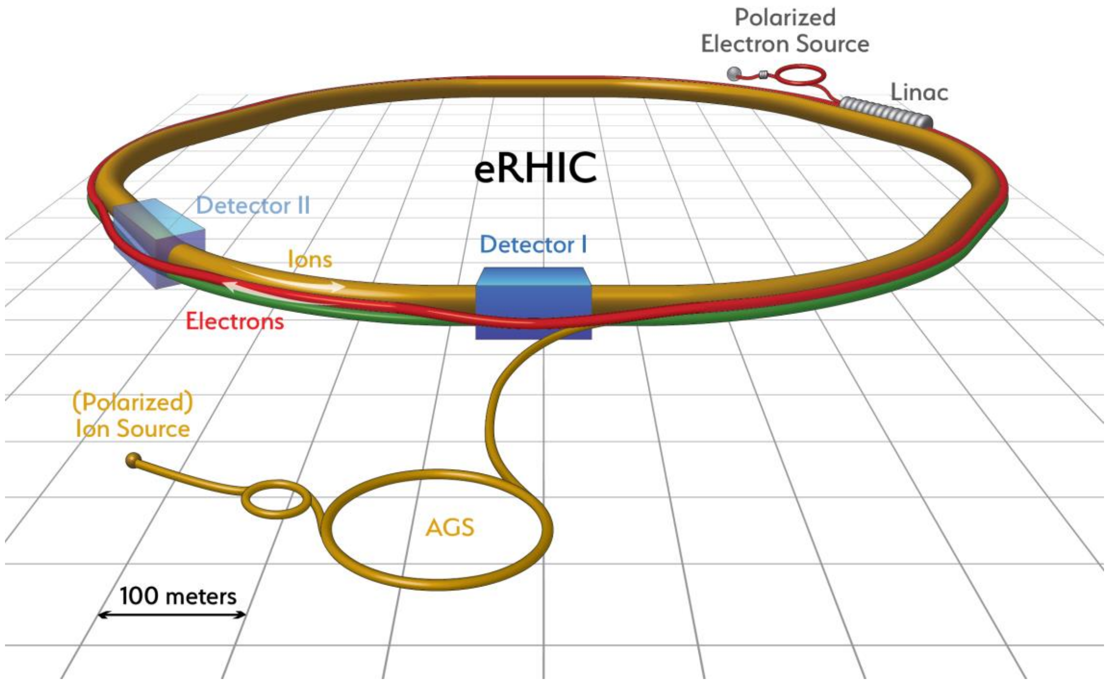
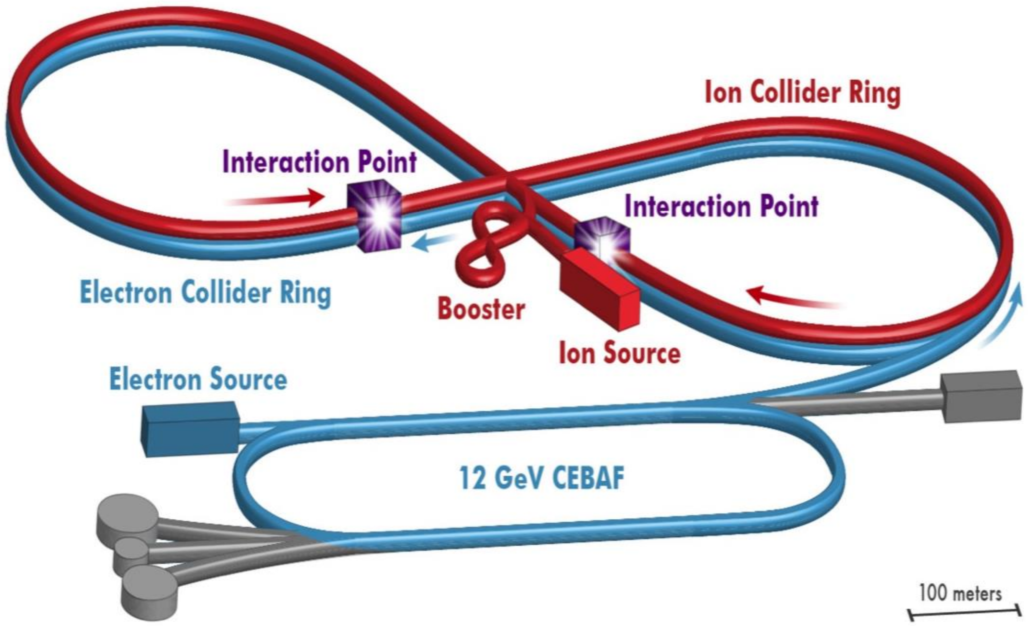
Electron Ion Collider designs





Lower luminosity
560 MHz RF
330 bunches
33 ns between bunches
Electron current up to 1.2A
Ion current up to 0.46 A

High luminosity
560 MHz RF
1320 bunches
10 ns between bunches
Electron current up to 2.4 A
Ion current up to 0.92 A

Low and Medium energy
476 MHz RF
1540x2 bunches
2 .1 ns between bunches
Electron current up to 2.8 A
Ion current up to 0.75 A

High energy
476 or 119 MHz RF
385 x 2 bunches
8.4 ns between bunches
Electron current up to 0.75 A
Ion current up to 0.71 A

Need detector response from 33 ns up to 2.1 ns to measure cleanly bunch by bunch

Bunch by bunch properties : example Compton polarimeter

eRHIC Linac Ring :

- several sources with different polarization used, need to separate 10 MHz beam structure

eRHIC Ring Ring – JLEIC

Energy (GeV)	Current (A)	1 pass laser (10W) Expected rate (MHz)	FP cavity (10 kW) Expected rate (MHz)
3	3	26.8	3100
5	3	16.4	1880
10	0.72	1.8	210

Only considering Compton cross-section: no background

EIC Detector R&D Progress Report June 2016

Problem: detect MIPs with bunch separation down to 2 ns

- Can bunches be temporally separated for all configurations (down to 2 ns)?
- Is it possible to uniquely associate a detected particle with the correct bunch crossing?
- Are there any scaling issues to go from 1 channel to 200 channels

(needed for electron polarimetry for example)

Detector with a signal faster than ~2 ns:

1 particle every bunch crossing per channel

(expected rate for 10 kW laser power >3 GHz per 5 cm^2)

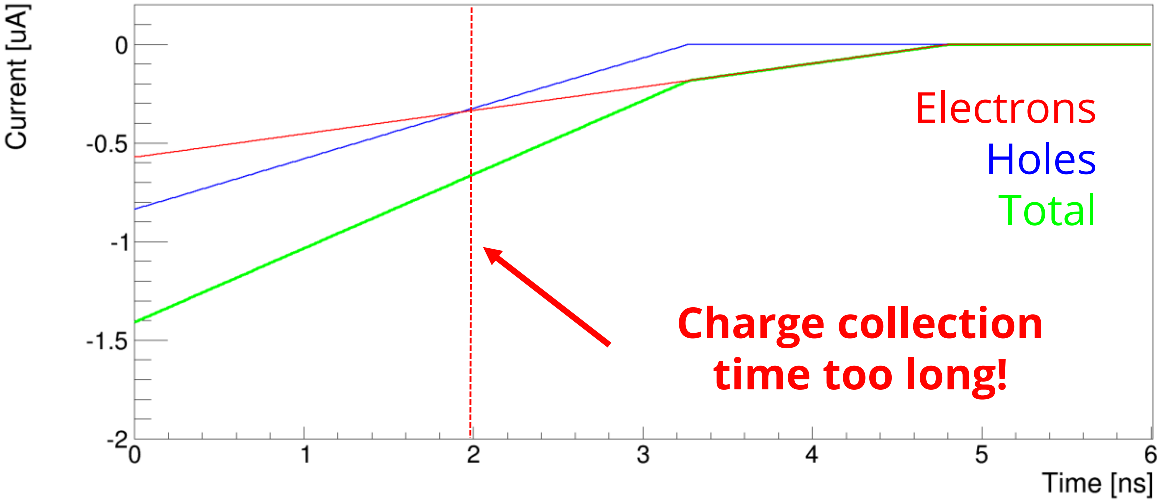
- Sensor, amplifier, digitizer, DAQ to be designed

Detector with a time precision better than ~2 ns:

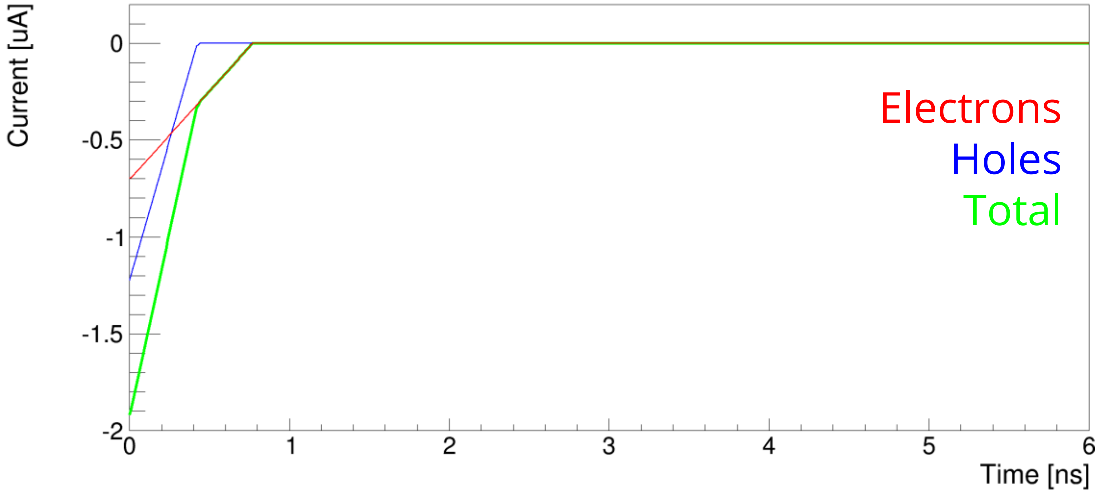
- Increased segmentation
- Less challenging detector requirements, but more channels
- Digitizer, DAQ to be designed

Is it possible to design a MIP detector with a signal shorter than 2 ns?

Diamond sensors are among the fastest available



500 μm scCVD diamond @ 800V



80 μm scCVD diamond @ 500V

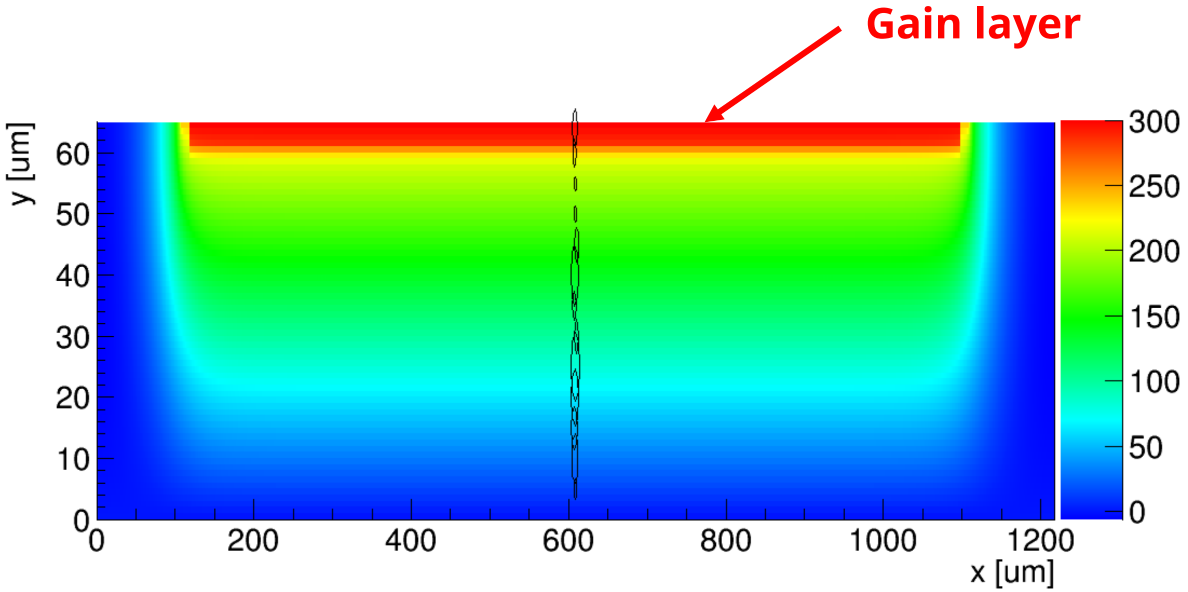
The collection time t_c depends on the thickness *d* $\quad t_c \sim {}^{d}/_{v_s}$

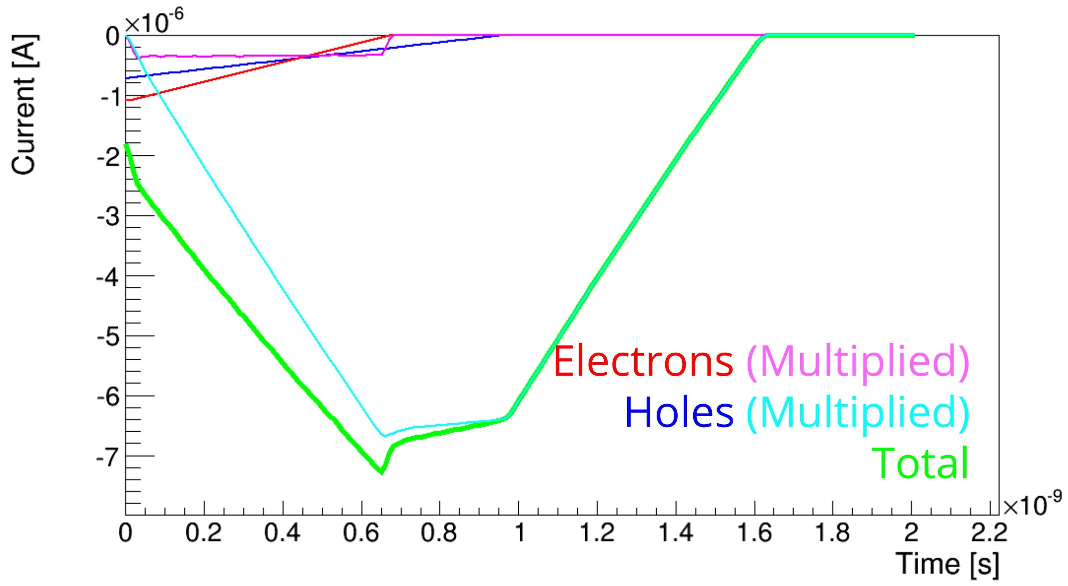
NOTE: the collected charge $Q_c = \int i\,(t)\,dt$ also depends on the thickness *d* $\quad Q_c \sim d$

However, the deep current mainly depends on the carriers' velocities, i.e. electric field $\quad |i_{MAX}| \sim {}^{Q_c}/_{t_c}$

Is it possible to design a MIP detector with a signal shorter than 2 ns?

Ultra Fast Silicon Detectors: as fast as diamond, but with a gain layer!



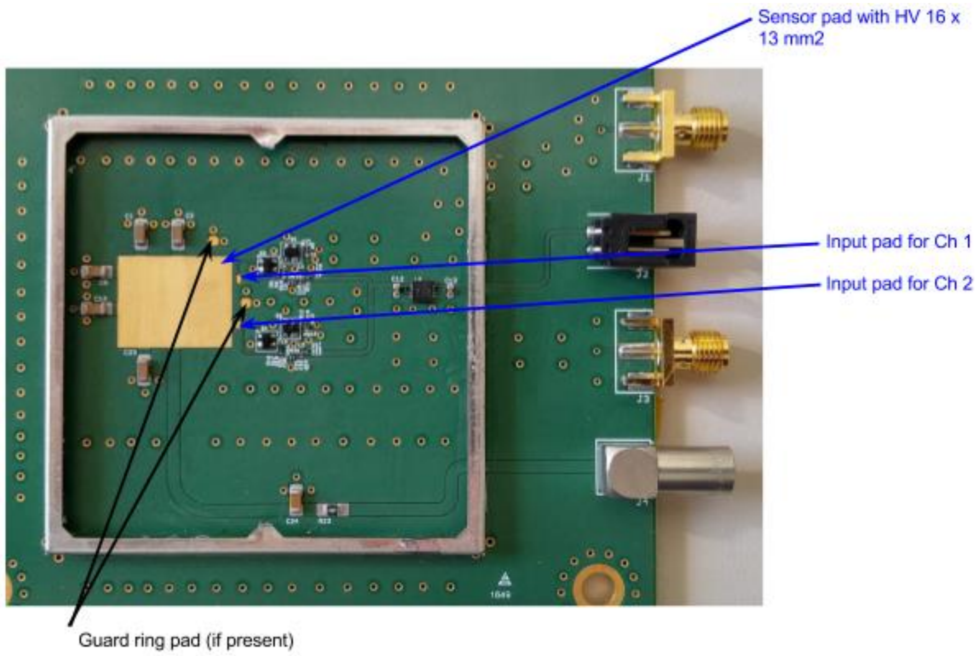


UFSD: 50 μm LGAD

Fast collection time (50 μm thick) and larger signals, thanks to the gain layer

Electronics for very fast detectors

A two channels board was designed and manufactured for the characterization of different solid state detectors.

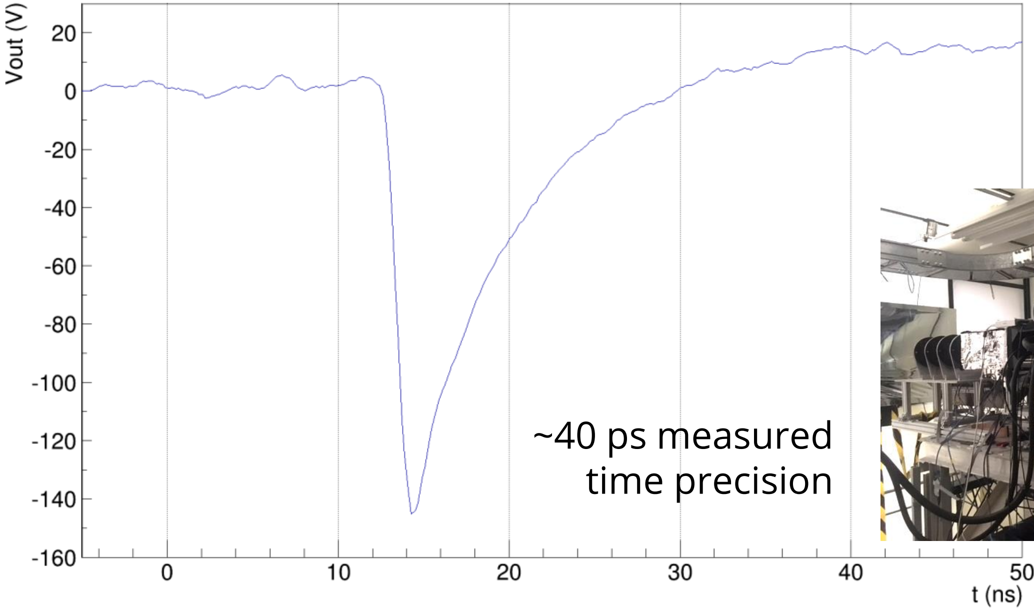


The board was optimized to achieve a good time precision with different sensors, however it can be modified to have an output signal shorter (but less precise)

Sensors up to 16x13 mm^2 can be glued and bonded.

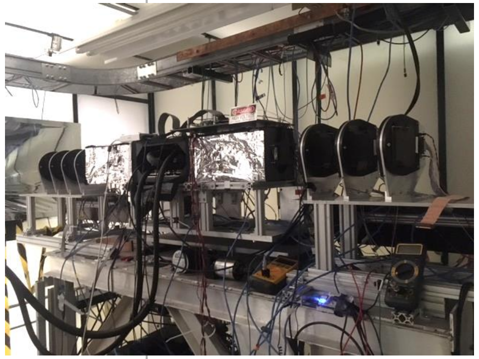
The components can be easily adapted to accommodate:

- Diamond sensors: ~1 nA bias current, both polarities, small signal
- Silicon seonsors: ~100 nA bias current, small signal
- UFSD ~100 nA bias current, ~ larger signal
- SiPM: ~ 5 uA bias current, large signal



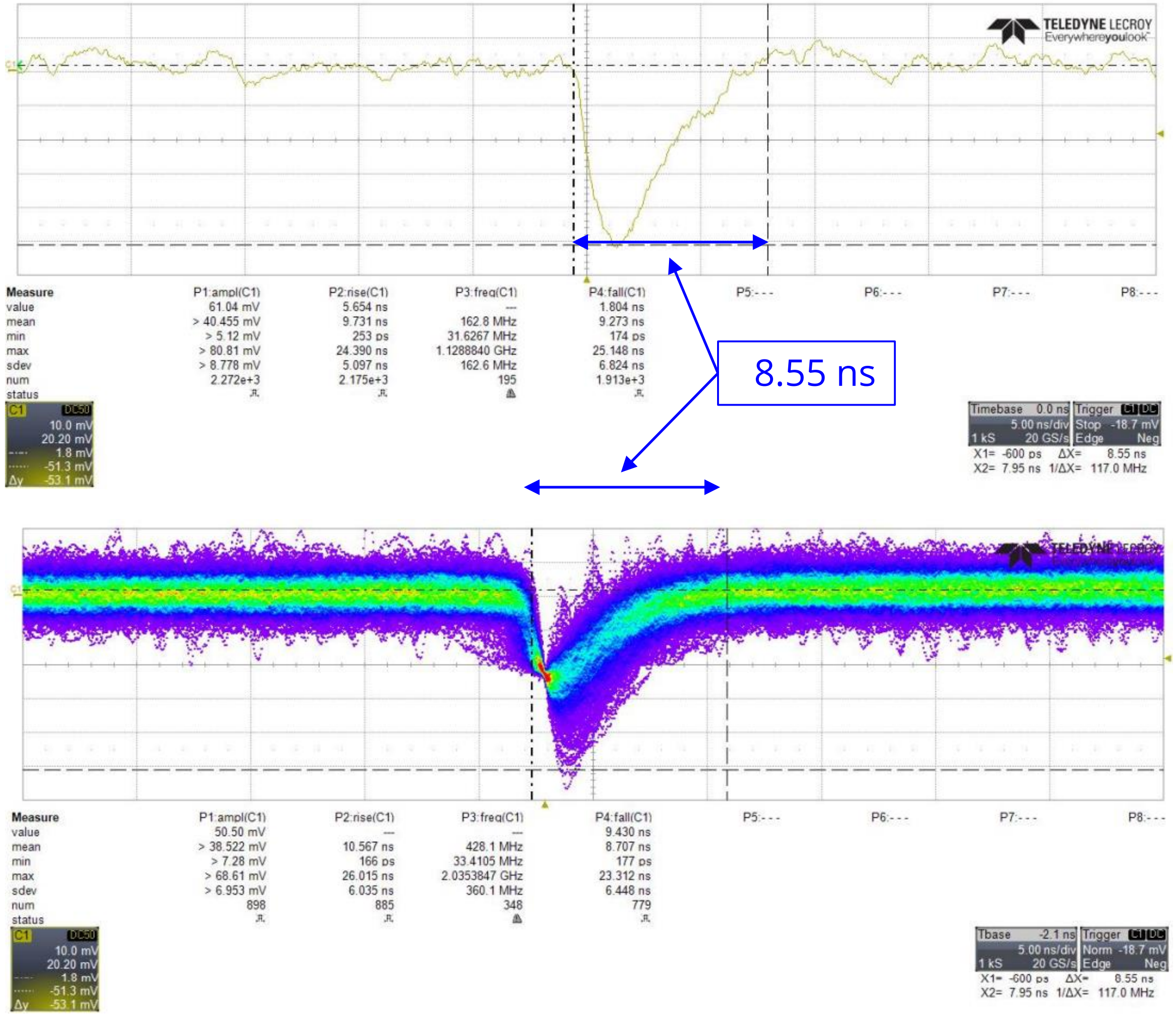
~40 ps measured time precision

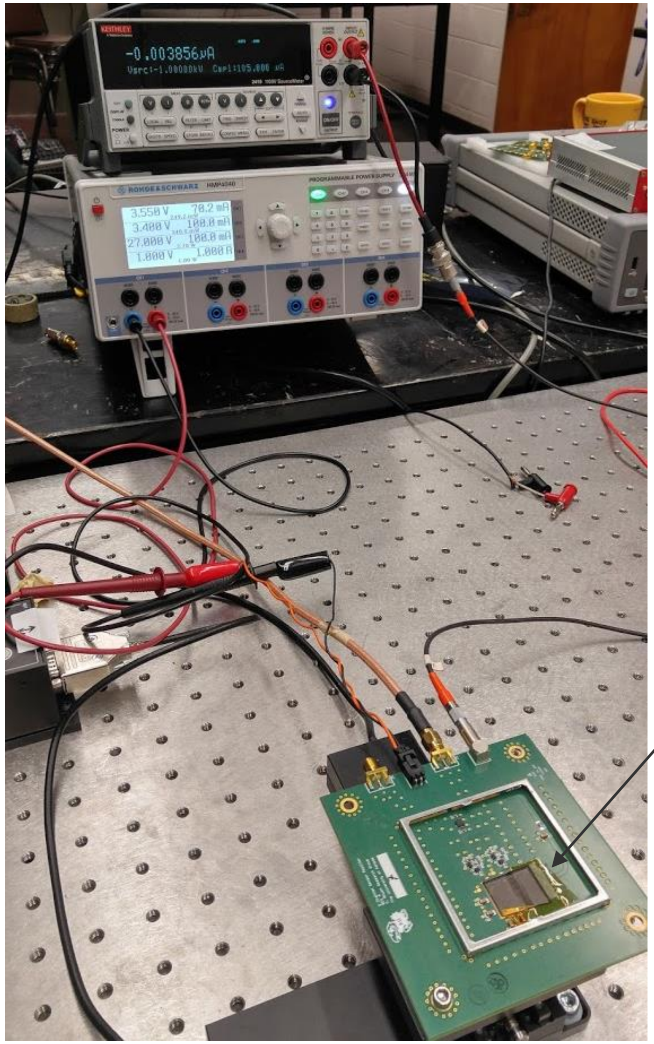
3x3 mm^2 UFSD MIP beam test @ Fermilab



Electronics for very fast detectors

This board was also used to test the performance of a diamond sensor using a Sr^{90} β^{-} source.

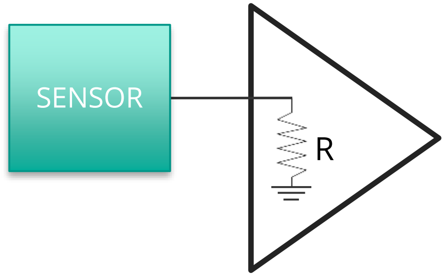


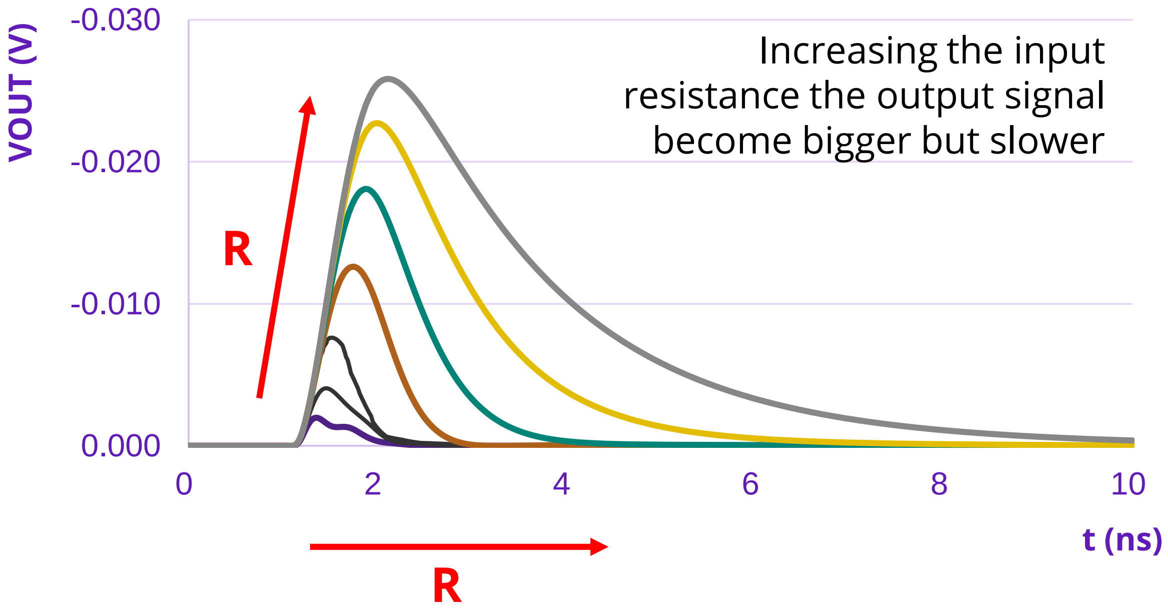


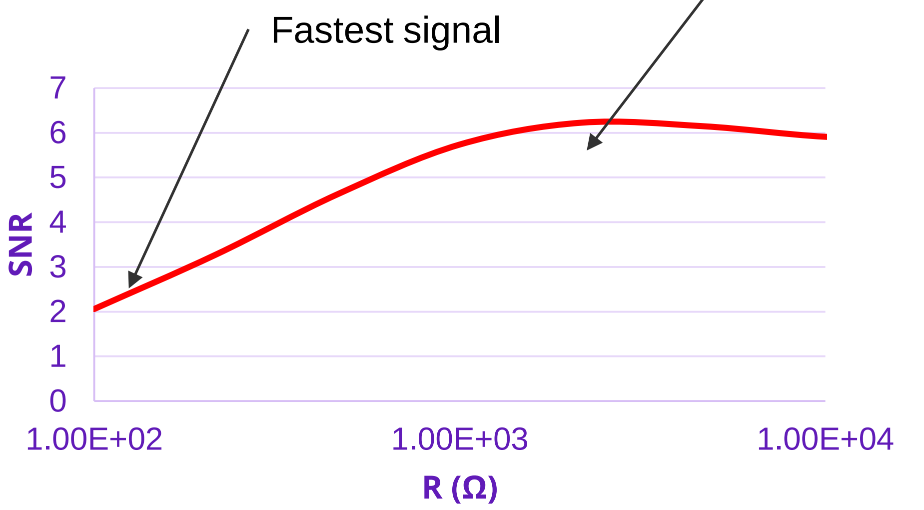
500 µm pcCVD diamond

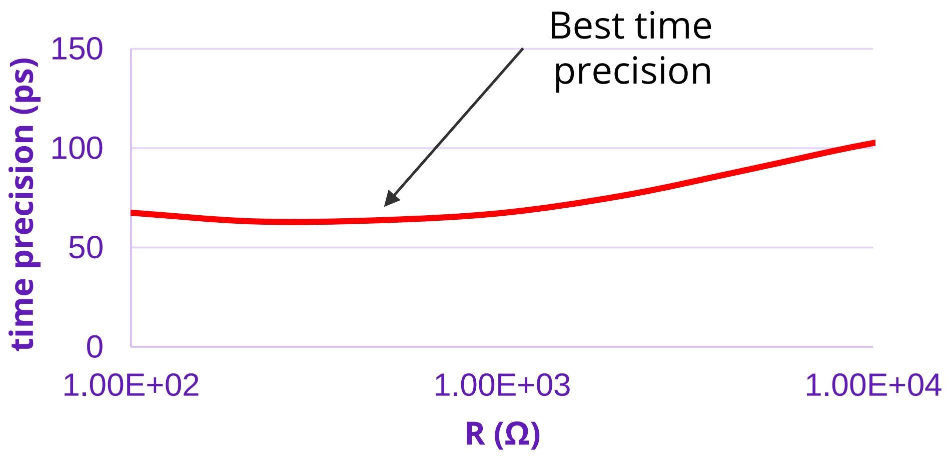
Is it possible to design a MIP detector with a signal shorter than 2 ns (modifying the KU board)?

The amplifier can be modified to have a faster signal but worse time precision.





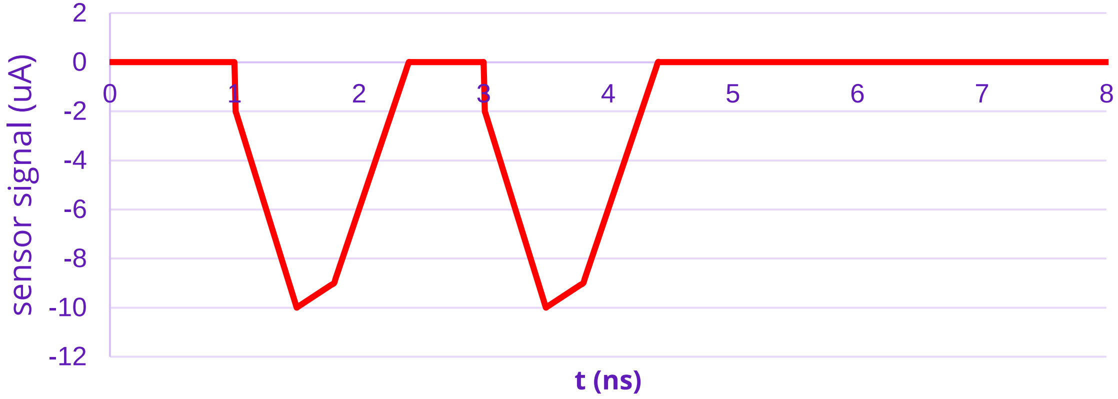


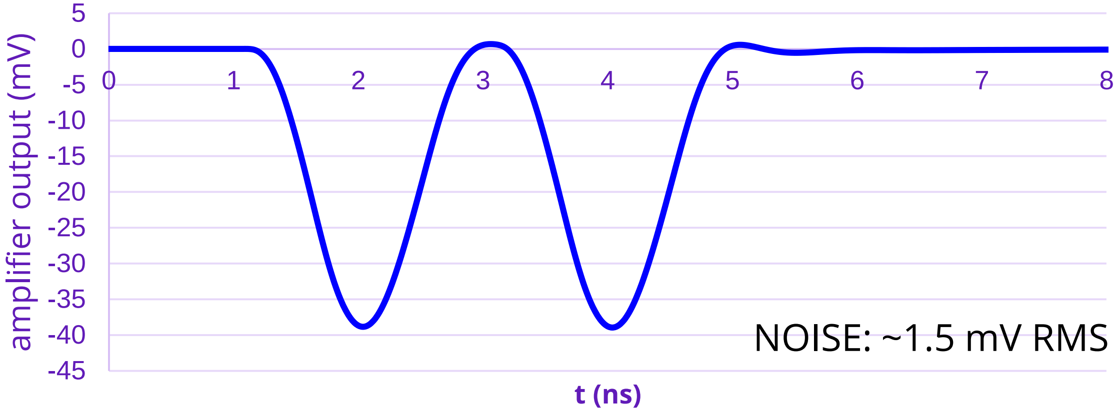


Is it possible to design a MIP detector with a signal shorter than 2 ns?

Simulated results:

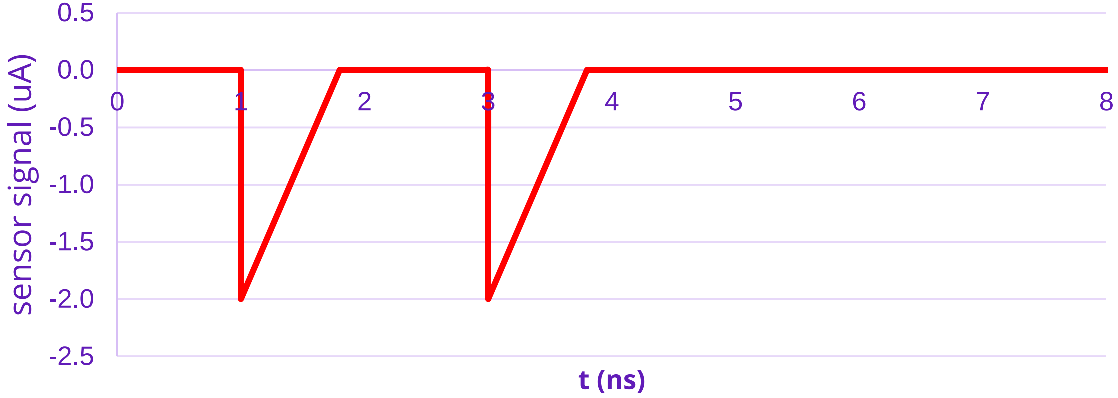
UFSD

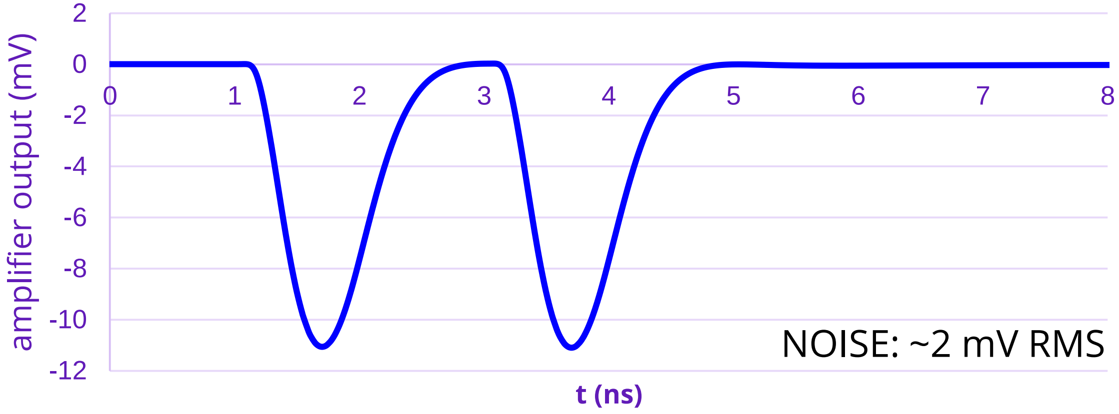




SNR ~ 25

80 μm scCVD diamond sensor

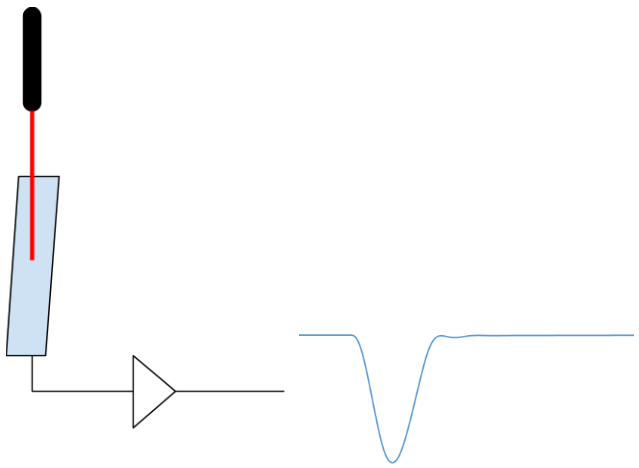




SNR ~ 5

Laser tests for silicon sensors

To test the high rate capabilities of the detector a laser pulse can be used

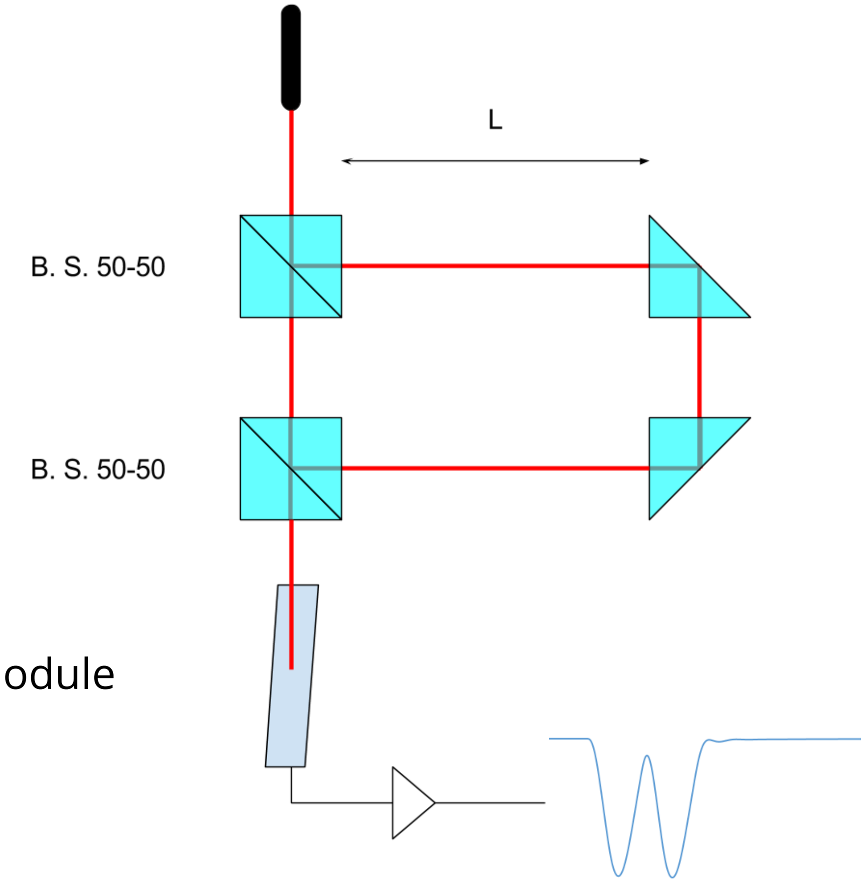


Infrared laser with fast pulses:

PILAS Gain-switched laser diode module

1060 nm, FWHM < 50 ps

Repetition rate < 10 MHz

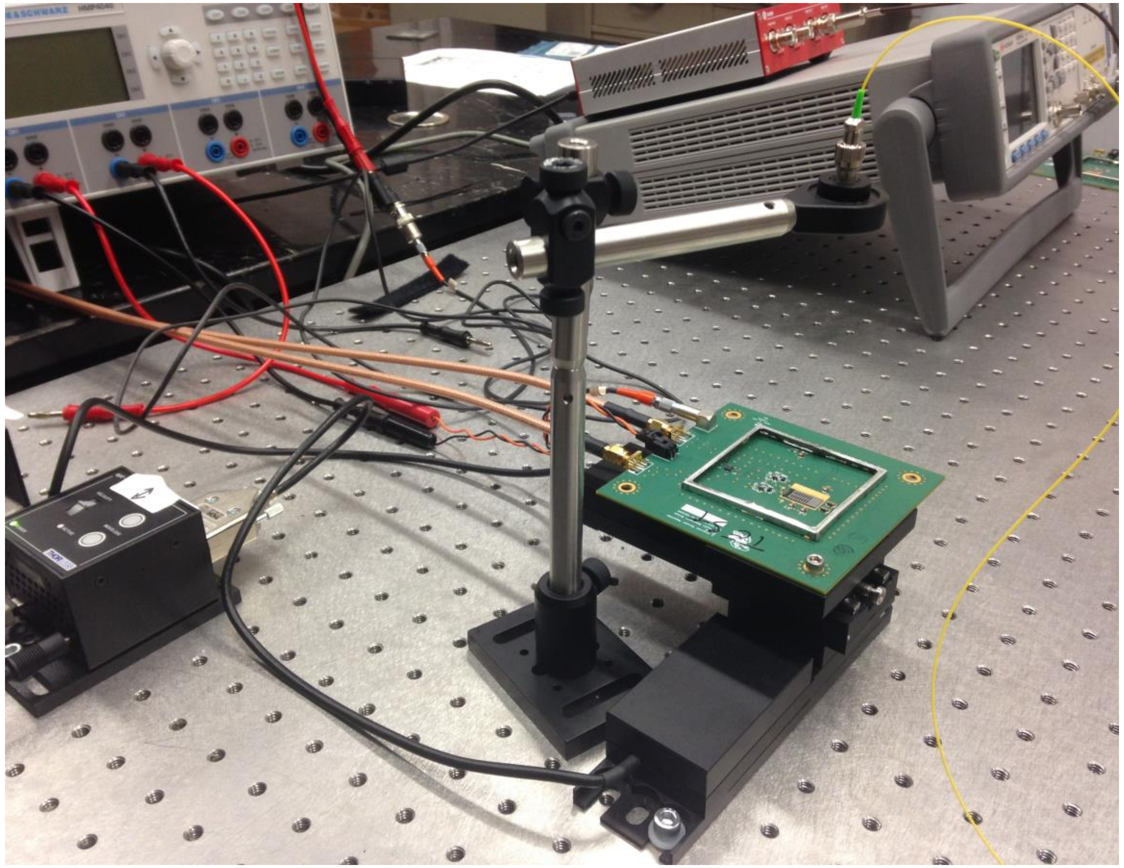


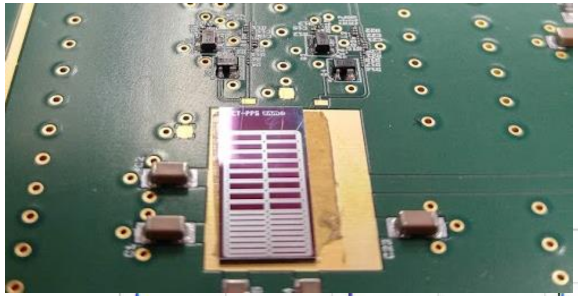
Using a chain of beam splitter it is possible to introduce several delays on the light path and produce two pulses with a separation of:

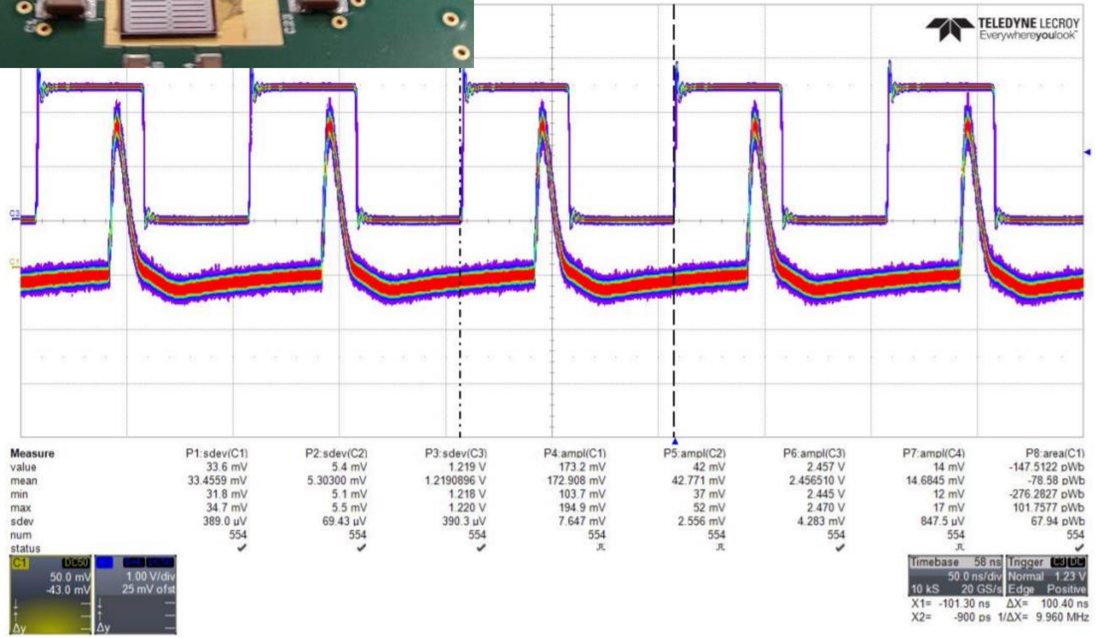
$$\Delta t \sim 2\,L\,/\,c$$

KU Capabilities

KU has already a test stand with a picosecond laser, but the maximum rate is limited to 10 MHz







1080 nm picosecond laser, 50 ps wide pulses with peak power > 100 mW set at 10 cm away from the sensor board
The support can be moved XY with micrometric accuracy

Timeline

2 months

Simulations and optimization

1 month

Modification of the existing electronics and tests with laser

2 months

Multichannel amplifier design

1 month

Beam test preparation and measurement

Budget request

Task		Amount direct (k$)	Amount with Overhead (k$)	Cumulative (k$)
Simulation	3 months postdoc	18	27.81	27.81
Amplifier modification	Production cost	5	7.725	35.535
Optimized amplifier design	3 months postdoc	18	27.81	63.345
Detector	Production cost	2.5	3.86	67.20
Multichannel amplifier	Production cost	20	30.9	98.1
Total		63.5	**98.1**	

Will participate if approved: 1 el. engineer (undergrad), 1 physicist (graduate) (funded by KU)

Budget scenario

Budget	Amount (k$)	Deliverables
Full	**98.1**	Optimized electronics and detector, beam test with multichannel amplifier
-20 %	**82.8**	Optimized electronics design, laser test with one channel modified amplifier
-40 %	**62.1**	Simulation and optimized amplifier design, laser or Sr^{90} test

Summary

Preliminary simulations show that short pulses can be generated with a reasonable signal to noise ratio

- Simulate different sensors, different size (thickness, capacitance, …)
- Modify existing amplifier and test with existing detector
- Design multichannel optimized amplifier
- Built multichannel amplifier
- Laser tests for high rate
- MIP (efficiency) test on particle beam

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Bunch by bunch properties : example Compton polarimeter

eRHIC Linac Ring :

- several sources with different polarization used, need to separate 10 MHz beam structure

eRHIC Ring Ring – JLEIC

Energy	Current	1 pass laser (10 W)		FP cavity (1 kW)	
(GeV)	(A)	Rate (MHz)	Time (1%)	Rate (MHz)	Time (1%)
3 GeV	3	26.8	161 ms	310	14 ms
5 GeV	3	16.4	106 ms	188	9 ms
10 GeV	0.72	1.8	312 ms	21	27 ms

Only considering Compton cross-section: no background

Example polarization lifetime JLEIC

Energy (GeV)	τ_{inj} (min)	τ_{opt_meas} (min)	$(P_{ave}/P_i)_{max}$ *
3	12	160	**0.94**
5	8	60	**0.88**
7	4	20	**0.85**
9	0.8	6	**0.89**
10	0.5	2.5	**0.86**

Polarization measurement of the order of second desired for short measurement at different point of the beam life

If same number of bunches and bunch-by-bunch polarization is needed, measurement duration has to be multiplied by number of bunches from 700 to 3300: high laser power cavity is needed

Main Parameters eRHIC ring-ring for Maximum Luminosity

E_p = 275 GeV, E_e= 10 GeV

		No Hadron Cooling		Strong Hadron Cooling	
Parameter	**Units**	**Protons**	**Electrons**	Protons	Electrons
Center of Mass Energy	GeV	100		100	
Beam Energy	GeV	275	10	275	10
Particles/bunch	10^{10}	11.6	31	5.6	15.1
Beam Current	mA	456	1253	920	2480
Number of Bunches		330		1320	
Hor. Emittance	nm	17.6	24.4	8.3	24.4
Vertical Emittance	nm	6.76	3.5	3.1	1.7
β_{x*}	cm	94	62	47	16
β_y*	cm	4.2	7.3	2.1	3.7
σ_x'*	mrad	0.137	0.2	0.13	0.39
σ_y'*	mrad	0.401	0.22	0.38	0.21
Beam-Beam ξ_x		0.014	0.084	0.012	0.047
Beam-Beam ξ_y		0.0048	0.075	0.0043	0.084
τ_{IBS} long/hor	hours	10/8	-	4.4/2.0	-
Synchr. Rad Power	MW	-	6.5	-	10
Bunch Length	cm	7	0.3	3.5	0.3
Luminosity	$10^{34}cm^{-2}s^{-1}$	0.29		1.21	

New eRHIC ring ring design : beam interaction frequency going from initial RHIC 10 MHz to 30 MHz with 330 bunches and 100 MHz with 1320 bunches in a 3.8 km ring

JLEIC Baseline New Parameters

CM energy	GeV	21.9 (low)		44.7 (medium)		63.3 (high)	
		p	e	p	e	p	e
Beam energy	GeV	40	3	100	5	100	10
Collision frequency	MHz	476		476		476/4=119	
Particles per bunch	10^{10}	0.98	3.7	0.98	3.7	3.9	3.7
Beam current	A	0.75	2.8	0.75	2.8	0.75	0.71
Polarization	%	80	80	80	80	80	75
Bunch length, RMS	cm	3	1	1	1	2.2	1
Norm. emitt., hor./vert.	μm	0.3/0.3	24/24	0.5/0.1	54/10.8	0.9/0.18	432/86.4
Horizontal & vertical β*	cm	8/8	13.5/13.5	6/1.2	5.1/1	10.5/2.1	4/0.8
Vert. beam-beam param.		0.015	0.092	0.015	0.068	0.008	0.034
Laslett tune-shift		0.06	7×10^{-4}	0.055	6×10^{-4}	0.056	7×10^{-5}
Detector space, up/down	m	3.6/7	3.2/3	3.6/7	3.2/3	3.6/7	3.2/3
Hourglass(HG) reduction		1		0.87		0.75	
Luminosity/IP, w/HG, 10^{33}	$cm^{-2}s^{-1}$	2.5		21.4		5.9	

Ring circumference : 2.4 km

Max number of bunches :3416
Number of bunches : 1540 * 2 two macrobunches
with 2.1 ns spacing between electron bunches